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ALL-TRANSISTOR HYDROPHONE PREAMPLIFIER

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ALL-TRANSISTOR HYDROPHONE PREAMPLIFIER *

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Abstract

An all transistor hydrophone preamplifier utilizing a field-effect transistor as the input element is described. The preamplifier utilizes four transistors, and is operated from a constant current supply through several thousand feet of cable, with dc power and output signal transmitted on a common pair of wires. Very good low frequency noise performance is obtained. Several of the problems encountered in the application of the field effect transistor are briefly discussed.

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Introduction

Despite the inherent advantages of transistors over vacuum tubes as signal amplifying devices, an all-transistor hydrophone preamplifier such as described in this paper is not feasible using conventional transistors because of the poor noise performance of conventional transistors at low frequencies with high impedance sources. The introduction of the field-effect transistor (FET), with its superior low-frequency high-impedance noise performance makes such a preamplifier feasible.

While the preamplifier described here is probably not the first of its kind (there is commercially available an all-transistor preamplifier with similar noise performance), it is felt that this preamplifier is representative of the state of the art and will be of considerable interest to those concerned with low frequency hydrophones and preamplifiers.

Block Diagram

A functional block diagram of the preamplifier is given in Figure 1. The preamplifier consists of four stages: an FET input stage which provides a high impedance to the source and a voltage gain of 3 to 6 db, a high gain

silicon transistor amplifying stage which provides in excess of 60 db of voltage gain, and two cascaded emitter follower stages for impedance transformation. Also shown on the block diagram are a feedback network for gain stabilization, and a decoupling network in the anode supply of the FET.

Schematic Diagram

The preamplifier circuit is shown in detail in the schematic diagram of Figure 2. The input impedance of the preamplifier is fixed by the input resistance, R_1 . The diodes D_1 and D_2 , in conjunction with the series resistance R_s , comprise a voltage limiting network in the input circuit of the FET, Q_1 , to prevent it from being damaged by excessive input voltages. FET's currently available have a wide range of parameter spreads in any particular type number; for example at constant electrode potentials and temperature, a five to one range of anode current for different units of a given type is common. In order to accommodate any unit of a given type in this circuit while maintaining proper circuit potentials, the shunt resistance R_A is included in the anode circuit of the FET. This shunt resistance must be adjusted in conjunction with the anode resistance R_3 to obtain the proper current through R_5 and the appropriate FET anode potential.

The FET, Q_1 , is direct coupled to the high gain silicon transistor Q_2 which in turn is direct coupled to the cascaded emitter followers Q_3 and Q_4 . The very high voltage gain from Q_2 is obtained by a form of positive feedback. Note that the supply side of Q_2 's collector load resistance is

not decoupled from the output signal; since the output signal is essentially the signal at the collector of Q_2 , less some slight attenuation in the cascaded emitter followers, the signal voltage across the collector load resistance is very small, and the collector load resistance is effectively an order of magnitude larger than its actual value. This, together with the high impedance presented to the collector circuit by the cascaded emitter followers, results in extremely light loading on Q_2 , and a very high voltage gain from Q_2 . The advantages of this may not be readily apparent; however, when it is considered that negative feedback is being applied from the output to the input of the preamplifier, and the preamplifier must have an even number of phase reversals to maintain the proper phase relationship between the input signal and the feedback signal, this results in a minimum number (2) of phase reversing stages with a minimum of coupling components and a minimum of phase distorting elements, all of which results in a circuit using relatively few components with a minimum of stability problems.

The gain stabilizing negative feedback is applied from the output of the preamplifier to the cathode of the input FET by the voltage dividing network R_F and R_2 . The shunt capacitance, C_F , across R_F provides high frequency compensation to eliminate any tendency to high frequency instability due to cable loading.

The two diodes in the common signal output and dc power supply circuit give protection against improper supply potentials. D_3 , a high conductance silicon diode provides protection against reversal of the supply polarity, and D_4 , a Zener diode, protects against excess supply voltage. D_4 is normally operating below its breakdown voltage.

Power Supply

As has been mentioned, the preamplifier output signal and dc power are conducted on the same pair of wires. This is done to minimize cable conductor requirements in a multiple hydrophone installation. Under these conditions, the power supply must be a constant current source, presenting a high impedance to signal voltages, rather than the usual constant voltage source. The power supply for the preamplifier is shown in Figure 3. The major components of the supply are the Zener diode voltage reference and the regulating transistor. The constant current supply operates from a 45 volt dc voltage source. The Zener diode holds the base of the transistor at a constant potential relative to the positive terminal of the voltage source; the emitter potential of the transistor is the same as the base potential, less the forward bias voltage of the junction; the emitter current is then essentially determined by the Zener diode voltage and the emitter resistor; the collector current is essentially equal to the emitter current. Thus the collector, or preamplifier current, is essentially determined by the Zener diode and the emitter resistor. In practice, the emitter resistor is adjusted for the desired current to the preamplifier. Under normal conditions, the preamplifier current is on the order of 5 ma., and the terminal voltage is on the order of 25 volts.

Preamplifier Performance

The following performance data are given for a preamplifier signal source hydrophone of -90 db re 1 volt/ μ bar sensitivity and 0.005 mfd capacitance (simulated by a 0.005 capacitor), and a preamplifier signal termination of

1000 ohms through an artificial line equivalent to several thousand feet of cable. The performance is summarized as follows:

Open loop gain -- in excess of 60 db.

Closed loop gain -- 40 db.

Frequency response -- 3 db down at 5 cps and 10 Kc.

Input impedance -- 6.8 megohms.

Output impedance -- approximately 50 ohms.

Maximum output voltage -- 1 volt rms.

Harmonic distortion at 1 volt output -- -60 db.

Dynamic range (per cycle bandwidth) -- in excess of 90 db.

Operating temperature range -- 30°C.

Self-noise (per cycle bandwidth) -- below equivalent sea state

"0" noise as shown in Figure 4.

Comments on Performance

The input impedance of 6.8 megohms is determined by the input resistor R_1 . It can be increased, if desired for other applications, by perhaps an order of magnitude. There is also a reactive component of input impedance due to shunt capacities which may be on the order of 100 pf, but this is negligible at the frequencies and impedances under consideration.

The maximum output voltage of 1 volt rms is available at frequencies up to about 1 Kc. This is reduced at higher frequencies by the capacitive loading of the cable. Higher maximum output voltage can be obtained by increasing the current through the output transistor.

The measurement of harmonic distortion was limited by the distortion present in the signal source. The distortion generated in the preamplifier could actually be lower than -60 db.

The limited operating temperature range of 30°C is a result of the temperature sensitivity of the FET in conjunction with operation from a constant current source. In this preamplifier the operating temperature range was chosen from 0°C to 30°C . The range can be moved up the temperature scale, say from 30° to 60°C , by the choice of components in the FET anode circuit. Degradation of performance outside of the operating temperature range is characterized initially by a reduced maximum output voltage as a result of saturation of the second stage Q_2 .

The equivalent input noise voltage shown in Figure 4 is essentially a function of the source capacitance. Holding the $M\sqrt{C}$ product of the hydrophone constant and varying C over perhaps a 10 to 1 range, the self noise to sea state "0" noise voltage ratio has been observed to remain fairly constant.

Preamplifier Physical Size

The size of the preamplifier essentially depends on packaging and system considerations. For purposes of illustration, a model constructed on perforated fibre-board is shown in the photograph of Figure 5.

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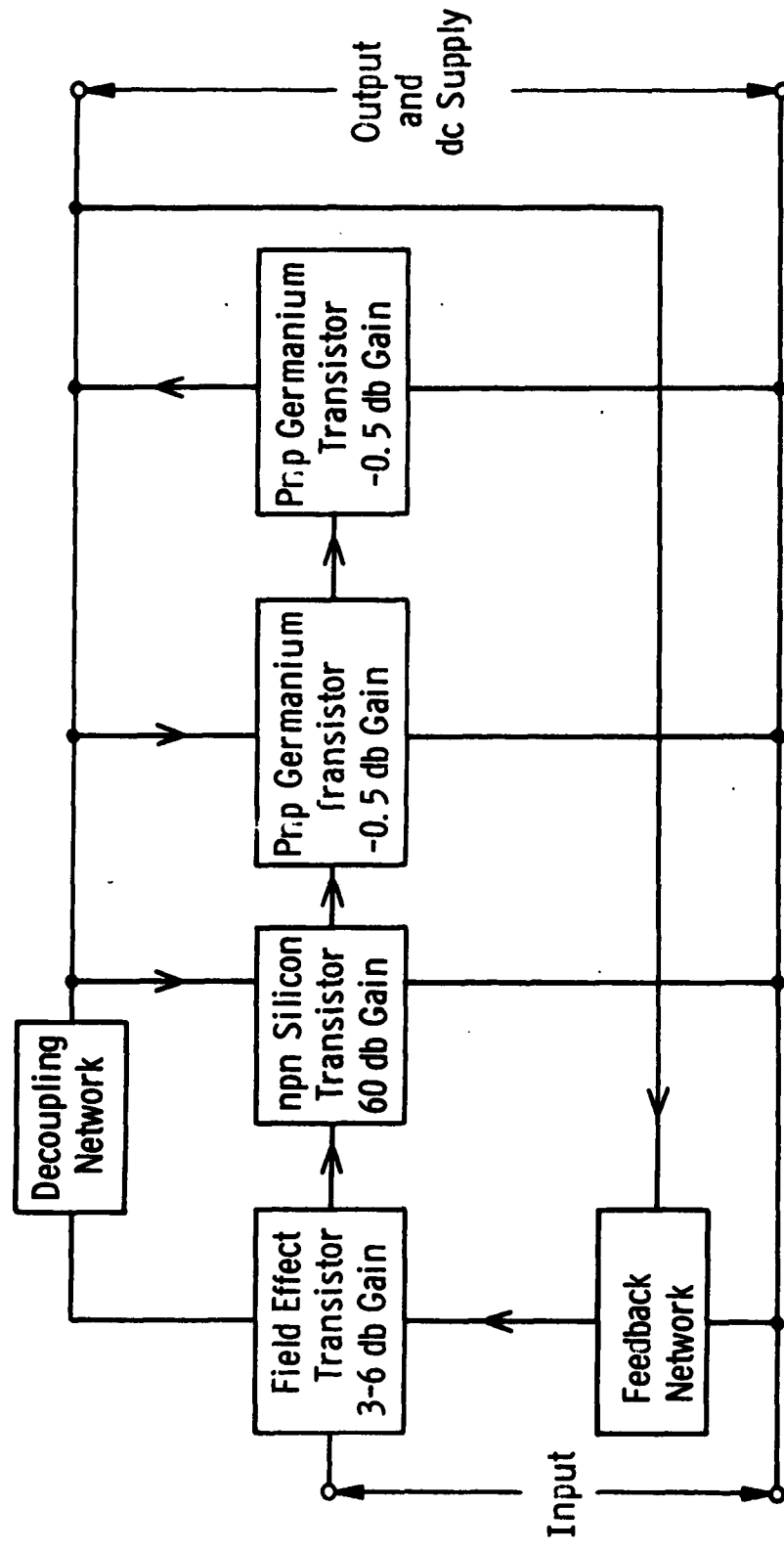
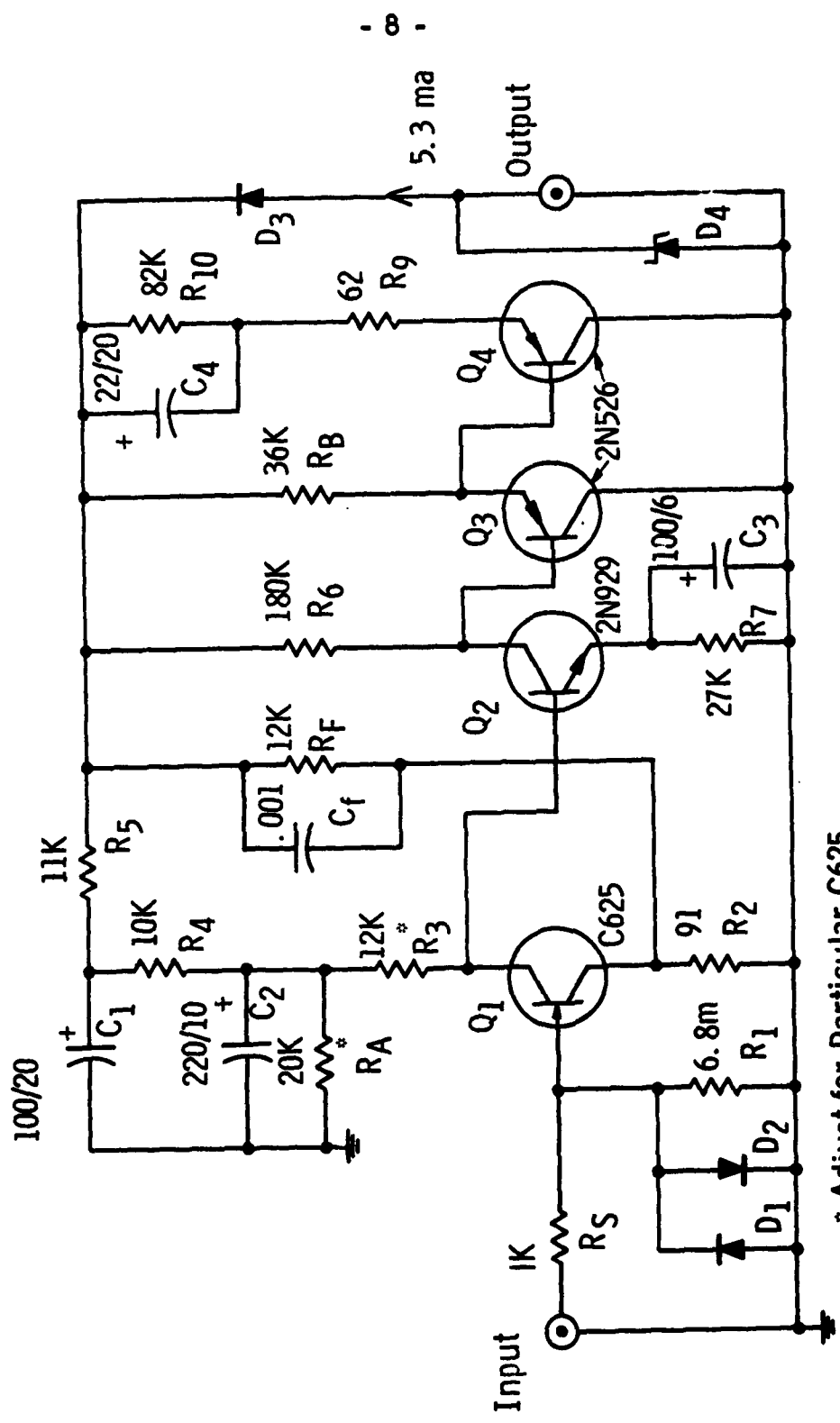


Figure 1 - Preamplifier Block Diagram

100, 520/20



* Adjust for Particular C625

Figure 2 - Preamplifier Schematic Diagram

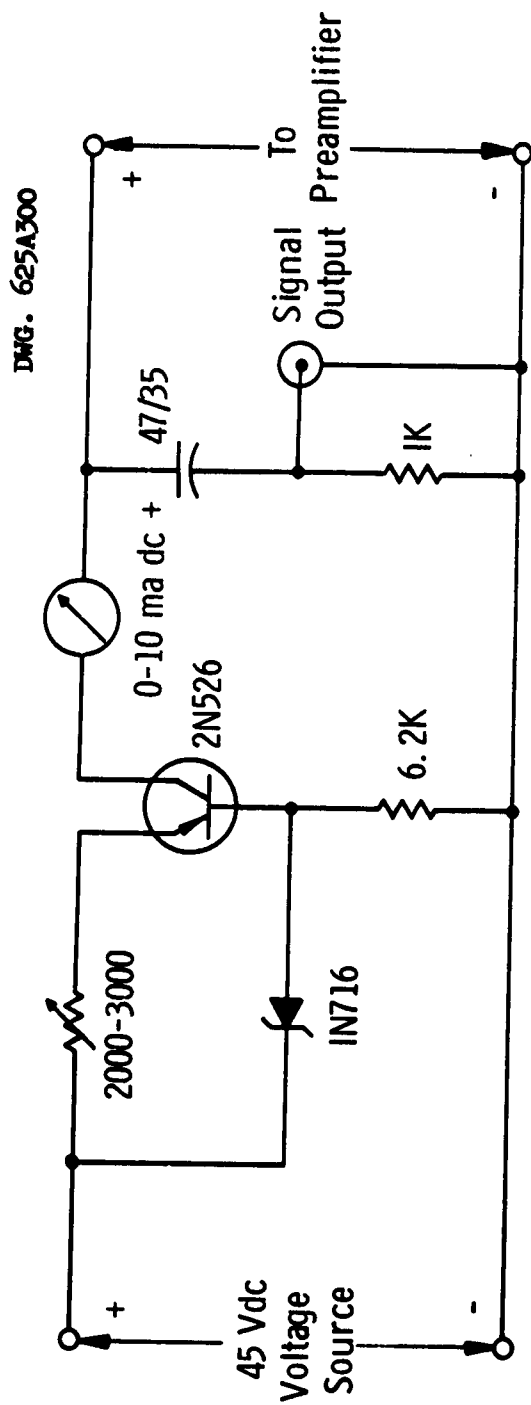


Figure 3 - Preamplifier Power Supply

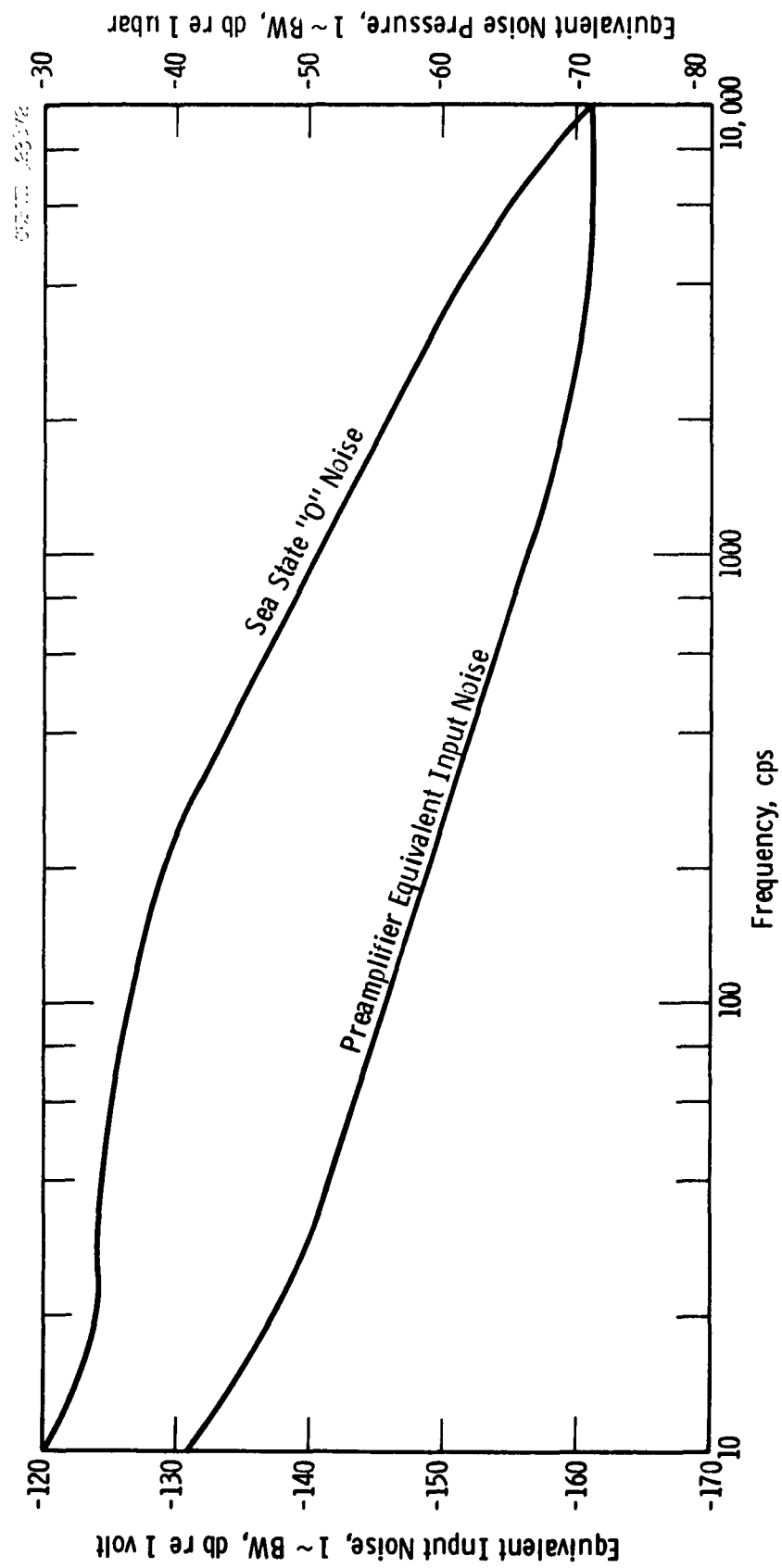
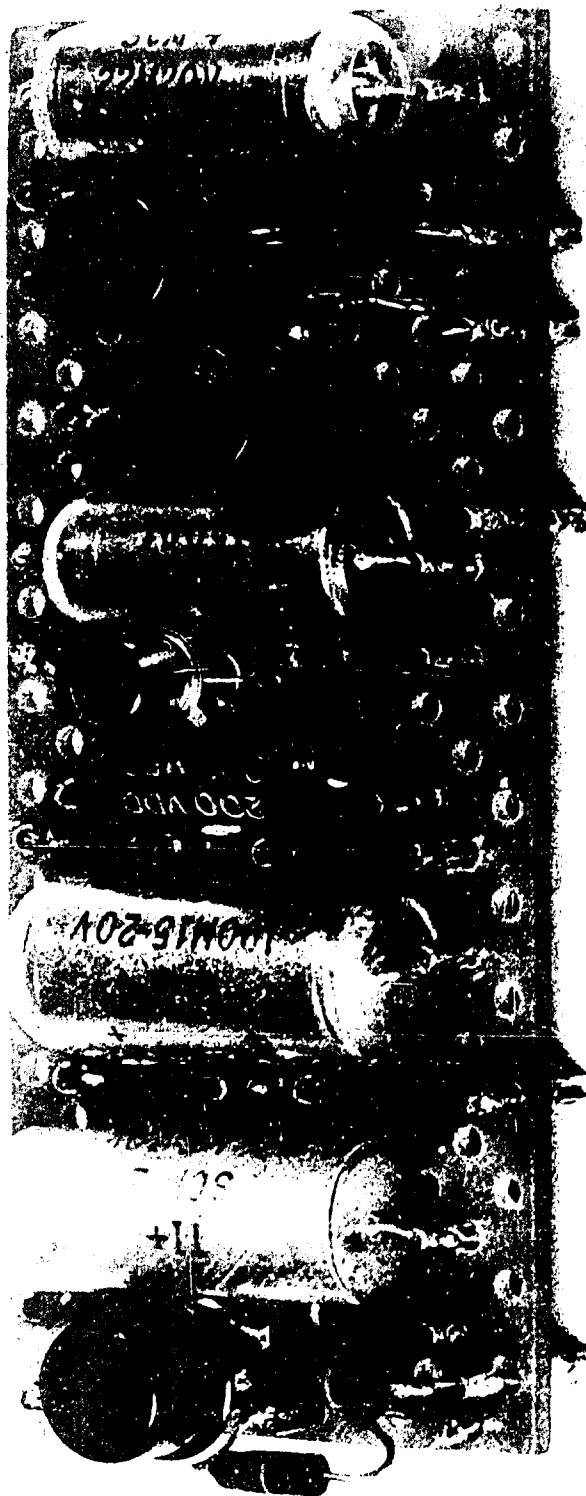


Figure 4 - Preamplifier noise performance



INCHES

Figure 5. Demonstration assembly of all-transistor preamplifier

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